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First assessment of interchange of humpback whales between Oceania and the east coast of Australia.

SOUTH PACIFIC WHALE RESEARCH CONSORTIUM,
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ABSTRACT

The interchange and isolation of individual humpback whales between wintering grounds of Oceania (South Pacific) and the east coast of Australia were documented by individual identification photographs collected from 1999 to 2004. Interchange was assessed using regional catalogues of fluke photographs, totalling 692 individuals from Oceania (represented by New Zealand, New Caledonia, Vanuatu, Fiji, Samoa, Tonga, Niue, Cook Island, French Polynesia and American Samoa) and 1242 individuals from Hervey and Byron Bay representing the southbound and the northbound migration along the east coast of Australia (EA). Overall, there were seven documented movements between EA and Oceania. Four instances of movement of four individuals were documented between EA and Oceania, all between EA and the closest breeding grounds of New Caledonia. A further three movements were recorded between EA and a small catalogue (n = 13) from the New Zealand migratory corridor. During this same period, 20 cases of interchange were documented among nine breeding grounds: French Polynesia, Cook Islands, Niue, American Samoa, Samoa, Tonga, Fiji, Vanuatu and New Caledonia. The low level of interchange between Oceania and the east coast of Australia and the movement across Oceania (including interchange across the boundaries of Areas V and VI) have important implication in understanding the stock structure and abundance of humpback whales in the South Pacific.

INTRODUCTION

Little is known of the movement of humpback whales between the east coast of Australia and the winter breeding grounds of Oceania. The first information on movements of humpback whales in the South Pacific came from the Discovery marking and recovery programme between 1950's and 1960's (Dawbin, 1959 and 1964; Paton and Clapham, 2006). The results mainly highlighted migration of the humpback whales between the Antarctic Area V and Australia and New Zealand. They also showed limited exchange between New Zealand and Australia, Norfolk Island, and Fiji with 3, 1 and 2 marks recovered respectively (Chittleborough, 1959; Dawbin, 1964). Dawbin (1966) concluded that the population of humpback whales passing along the east coast of Australia was part of the population of Area V (130°E to 170°W) known as Group V.

Dawbin (1959) also reported the presence of whales in several islands groups of Oceania (Dawbin, 1959) as part of the "Discovery marking" program used to track the journeys of humpback whales. However, some inherent

problems with the programme included the limited marking of whales in Oceania, the fact that this technique relies on whales being killed to recover Discovery marks, and the lack of whaling activity in Oceania during this period (apart from some limited whaling in Tonga). These problems are likely to have contributed to the lack of any recorded movement between or within the islands of Oceania from the Discovery programme. Thus it was not until photo-identification studies were started in the 1990s that movements of individuals were first reported (Abernethy et al., 1992; Hauser et al., 2000; Garrigue et al., 2001; Poole, 2002; Gibbs and Childerhouse, 2004). These recent studies suggest that the South Pacific region contains several populations that inter-mingle to a variable, but probably small, degree (Garrigue et al., 2000 and 2002). Group V humpback whales have recently been divided into three sub-stocks known as Breeding Stock E(i), those wintering off the Australian east coast, E(ii), those wintering around New Caledonia, and E(iii), those wintering around Tonga. (IWC, 1998; Garrigue et al., 2006; Olavarria et al 2006). E(i), the Australian east coast population is thought to be the largest of these sub-stocks.

The regular comparison of flukes of humpback whales assembled in regional catalogues highlighted movements within Oceania (Garrigue et al., 2002, Garrigue et al., 2007) and allowed the estimation of rates of interchange to be made between the islands groups. Opportunistic documentation of movement between Oceania and the migratory corridors of New Zealand and Australia have also been reported (Garrigue et al., 2000) but the rate of exchange has only been calculated for New Zealand (Garrigue et al., 2002).

To assess the population size of humpback whales in the South Pacific, information is needed on the rate of exchange between the east coast of Australia and Oceania. To prepare for a systematic comparison of fluke catalogues from eastern Australia (EA) and Oceania humpback whale fluke identification catalogues, a meeting was held between 29th of November and 1^{rst} of December 2006 in Noumea, New Caledonia. The goal of this comparison was to quantify and compare rates of interchange between Oceania and EA in order to better estimate abundance and describe stock structure of the humpback whale populations inhabiting this western and central parts of the South Pacific.

Here we report on the initial result of comparisons between catalogues representing East Australia and nine regions of Oceania. This will include an exploration of the nature of this interchange (e.g. sexes, ages). More detailed analyses and comparisons utilising genetic tagging and differentiation techniques are also underway to better understand this interchange (e.g. differences in interchange between sexes, ages or directions of movements). Overall, it will provide a better understanding of the population structure of humpback whales in the South Pacific and allow for an improved and more robust estimate of abundance for humpback whales in the South Pacific.

MATERIALS AND METHODS

Catalogues

Only the fluke identification catalogues currently held by members and affiliates of the South Pacific Whale Research Consortium (SPWRC) working in Oceania and East Australia were considered in this study. Photo-identification of individual whales was conducted within each study site by each primary investigator. Regional catalogues of all individual humpback whales identified from photographs of the unique markings on the ventral surface of their tail flukes were compiled (Katona et al., 1979). Original photographs were collected during the study period on both film and/or digitally. In the former case photographs were scanned at the highest possible level of resolution for digital storage and exchange.

For the purpose of this study a synoptic period was defined encompassing all the years from 1999 to 2004 and is hereafter referred to as the synoptic years. Each catalogue owner undertook an initial screening of his/her own catalogue and removed all extremely poor quality photographs. Each regional catologue was then reconciled within and between years for the study period, in order to retain only the single best fluke photo-identification for each individual. These reconciled regional catalogues of unique individuals were compared to each other during annual meetings of the Consortium (SPWRC, 2001, 2002, 2003, 2004, 2005) using a systematic pair-wise comparison. This led to a fully reconciled catalogue for Oceania named the “Oceania catalogue”. For the purposes of this match it is composed of whales flukes from New Caledonia, Tonga (comprising Vava’u, Eua, Ha’apai, Niuatoputapu), Cook Islands, French Polynesia, Vanuatu, Fiji, Niue, Samoa, American Samoa and New Zealand.

The regional fluke catalogues of Hervey Bay (HB) and Byron Bay (BB) represent the southbound and northbound migrations of humpback whales respectively on the east coast Australian migratory corridor (Franklin and Franklin 1992-2005, Paton et al 2006). These two catalogues were reconciled for each study area

within and between years using two independently evolved fluke matching systems. The BB stratified matching systems is based on individual fluke characteristic features such as the proportion that is black, characteristics of the centre and characteristics of the trailing edge of the fluke. The HB matching system utilises an ordered array of coded fluke characteristics and markings, with emphasis on the trailing edge and notch, providing a continumn of discrete stratified categories. These systems were applied to each respective catalogue to reduce the number of comparisons required in the matching process (Paton et al., 2006). These two reconciled regional catalogues of EA were compared, leading to a single fully reconciled catalogue composed of unique individual humpback whales named the "East Australia catalogue".

Time selected photographs were then compiled in two electronic catalogues (EA and Oceania) with attached information for each region.

Quality control

Following the Noumea meeting, the participants agreed that there was a need to be review all photographs used in this comparison, following a set of quality control standards in order to minimise bias in the estimation of abundance. All images were reviewed according to a standard set of quality control criteria that were originally developed for the SPLASH programme in the North Pacific. This is a scoring system based on objective quality measures of the images that are irrespective of distinctiveness of the fluke (Calambokidis, 2001). It consists of five quality criteria to score photos between 1-5 in each category and then agreed combinations of criteria are used to accept or reject photos. All the images were graded from the highest quality (1) to the lowest quality (5). These five criteria categories were (i) proportion of the fluke visible, (ii) fluke angle, (iii) the lateral angle of the photographer, (iv) exposure quality, and (v) contrast quality as described in Calambokidis et al., (2001). An image that received one or more 4 or 5 scores in any of the five categories was considered to be of insufficient quality for a representative comparison of resight rates between sites and was therefore removed from the data set.

During the implementation of the SPLASH program, quality control was screened using quality scores to try and develop a threshold that would remove any errors apparent in the data. For this two matchers conducted blind comparisons in matching exercises that allowed for the evaluation of matching success. The rate of missed matches was examined with respect to quality and it was found that most of the missed matches were of lower quality photos, although it still happened with good quality photos. During the SPLASH programme, the same quality criteria were applied for most sites but some exceptions were made for sampling in areas that were believed to be under sampled or had a high portion of poor quality images from a small number of photos.

As recommended by Friday (Friday, 1997; Friday et al., 2000), the quality control review of all catalogues was undertaken by a single researcher familiar with cetacean photo-identification (RC) in order to ensure consistency. This process was undertaken in December at the University of Auckland using digital images. Part of the Tongan catalogue was also scored by an experienced, independent assessor from the SPLASH programme to investigate consistency of scoring between the two projects.

Matching process

Matching was undertaken using electronic images of consistent standard. The matching method used was a 'rational' rather than exhaustive pair-wise comparison. This meant that flukes in the Oceania catalogue were ranked (ordered) in a continuum from all white to all-dark. As in SPLASH, a single match was undertaken as comparisons of each fluke from EA was made to all Oceania photographs until the reviewer was satisfied that no further match was possible, i.e., all white flukes were not matched to all dark flukes. A record was kept for each EA photographs of which parts of the Oceania continuum it had been matched. This was used to measure effort of the matching and allow checks of the matching process to be made.

The regional Oceania catalogues were sorted into three approximately equal-sized groups to allow more efficient matching by those familiar with each region. Group one was composed of Cook Islands and French Polynesia, group two encompassed Tonga (only Vava'u) and group three comprised all the rest of the Oceania catalogue (New Caledonia, Niue, Fiji, Samoa, American Samoa, Vanuatu, Tonga (except Vava'u), New Zealand).

RESULTS

Quality control and matching

The catalogues submitted for quality control screening contained 995 photographs for Oceania and 1,844 photographs for EA. Overall, 30 % (897) of all photos were scored as a 4 or 5 in one or several quality control criteria and thus were excluded from the final matching dataset (30 % for EA and 34 % for Oceania, Table 1). The rejection rate of the regional catalogues ranged from 0 to 60 %.

Table 1 presents the number of individual whales photo-identified in each regional study site after quality control had been undertaken. The screening process resulted in two quality controlled and reconciled catalogues for EA and Oceania that contained 1,242 and 692 individually identified humpback whales respectively.

A full pair-wise of EA with Oceania would have required over 860,000 matches. Using rational pair-wise comparison of the two catalogues reduced the number of comparison required by 165,052 or 19 % of the total of comparison possible, resulting in a total of 710,558 comparisons. The matching was accomplished in 300 hours. More than three-quarters of the flukes in the EA catalogue (76 %) were compared to 86 % of the Oceania catalogue. Only a small percentage of the EA photographs (7 %) were compared to the 18 % of the Oceania photographs that were predominantly black.

Interchange

The comparison of the EA and Oceania catalogues resulted in seven matches between these two regions (Table 2). Only four individuals from EA were resighted in the breeding grounds of Oceania; all of which were first observed in New Caledonia (Table 3). Two of these were resighted in Hervey Bay during the southbound migration and the other two were resighted in Byron Bay on the northbound migration. All four whales were identified as males by molecular techniques (Gilson et Syvanen, 1998; e.g., Garrigue et al., 2004). Most of the resighted whales were observed in more than one year in New Caledonia with one observed in three different years, two sighted in two years and one identified on a single occasion. These whales were encountered in different types of social group (single, pod of two and reproductive pod) (Table 3). Interestingly two of these whales were first identified as young animals but not calves (judging on their apparent size). One of them was encountered with a female and was hypothesised to be a yearling as the microsatellites analysis identified them as a potential mother and calf pair.

The comparison of East Australia and the small catalogue from the New Zealand migratory corridor resulted in three matches. Two of these three whales were observed only once at each site, the third one was observed three time in EA (Table 3). Interestingly these three whales were first sighted in Cook Strait (New Zealand) during the northbound migration in 2004 and resighted in Hervey Bay during the southbound migration (Table 3). Two of them occurred on the same year with inter-sight intervals of 87 and 92 days. Both were sexed as male, one by molecular analysis and the other by field observation supported by photo-identification of the genital area (TF).

Among wintering grounds within Oceania, there were 20 resights, of which 16 involved interchange with Tonga. Details of interchange within Oceania are discussed elsewhere (Garrigue et al., 2007a).

DISCUSSION

Quality control and matching

There is a need to strike a balance between accuracy and precision when selecting the quality of photographs to be included in a matching process. This choice has potential implications for any population estimates as the use of all photographs, irrespective of quality, may positively bias the estimate (Hammond, 1990). Thus in this study a quality control system was used to screen the EA and the Oceania catalogues.

The comparison highlighted the need to consider both the similarities and differences in large-scale oceanic comparisons. The matching process of the South Pacific humpback whales flukes included only 20 % of the Oceania catalogue for the full black and half black & white flukes, whereas the mostly white flukes involved 86 % of the Oceania catalogue. This has parallels with the SPLASH categorisation system, except that the relative frequencies for the two colour pattern types are broadly reversed in the North Pacific. In SPLASH 50-60% of the catalogue is involved when matching the full black flukes; 30-40% of the catalogue for the half black & white; and only 10-20% of the catalogue for the primarily white flukes. Whereas the SPLASH project emphasises the importance of the trailing edge as one of the major features given the high proportion of black

flukes in the North Pacific, South Pacific matchers placed an emphasis on the notch of the fluke as one of the major features in the high proportion of white dominated flukes.

Finally, we note the importance of meeting in advance of commencing a the large-scale matching project in order to consider an efficient and unbiased design for quality control and the structure of the comparison. The rational pair-wise comparison, even if a full comparison would be preferred, saved approximately 20% of the matching time in this project. Given that it would be extremely unlikely that a predominantly black fluke photograph would match a fluke that is largely white, we considered that the rational pair-wise method was a much more efficient method.

To test the accuracy of the matches a double blind test was opportunistically conducted on a subset of the catalogues, including part of Byron Bay and part of New Caledonia. An inexperienced matcher found the same results as the experienced matcher for the same images (2 matches between BB and NC).

Interchange and isolation

The results presented here represent the first systematic comparison of individual movement across the migratory corridors and wintering grounds of humpback whales thought to feed in Areas V and VI of the Antarctic. The three matches documented between EA and New Zealand suggests an even stronger connection between these two corridors than previously thought based on Discovery marking and recovery (Table 3). However, the catalogue for the New Zealand corridor remains small (reflecting the low level of recovery of this stock, (Gibbs and Childerhouse, 2006) and the relatively high rate could reflect an episodic, rather than ongoing, exchange.

With only four individuals resighted between EA and the breeding grounds of Oceania the level of interchange was surprisingly small, given the relatively large catalogues used in this comparison, and provides strong evidence for subdivision with Breeding Stock E (formerly Group V). By comparison the rate of interchange within the different regions of Oceania for the same period is five times higher, highlighting the small rate of interchange between Oceania and EA on both the northern and southern migrations (Garrigue et al., 2007). There the 20 resightings of whales among breeding grounds of Oceania indicate a limited, but not insignificant, interchange across this vast region. Tonga showed the highest levels of interchange to other breeding grounds both to the east and the west, confirming the movement of individuals across the borders of the Antarctic Areas V and VI.

Nevertheless, it is worth noting that all the interchanges between EA and Oceania were found with the nearest of the Oceania breeding grounds in New Caledonia. This area exhibited roughly the same rate of exchange within the other Oceania grounds for the same period (with five matches all located in the southwestern part of the Pacific including Vanuatu and Tonga) (Garrigue et al., 2007).

The results of this study are likely to be more representative of the primary patterns of movement between EA and Oceania as it included major breeding grounds and two important migratory corridors, however our systematic and synoptic comparison was not exhaustive and did not include all of the connections reported in previous photo-identification analyses. Other matches between EA and Oceania are known outside of the synoptic years and/or outside the catalogues considered here (e.g. previously reported match from an opportunistic comparison of catalogues between NZ and Tonga; Constantine et al., in press). Unpublished data on a match between Tonga and another catalogue held by one of the authors (DB) from east Australia situated on the southbound migration (Ballina, New South Wales) indicates that interchange does exist between Oceania and other parts of East Australia. Future work will focus on planning for an expansion of the synoptic period to investigate matches over a longer time frame.

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Table 1 – Summary of photographs of unique individuals received, rejected, and accepted by study site between 1999 and 2004.

Region	number of photos submitted	number of photos rejected	Percentage of rejection	Number of photos accepted
Byron Bay	598	183	31	415
Hervey Bay	1246	375	30	871
Catalogue of East Australia	1844	558	**30**	**1242**
French Polynesia	230	107	47	159
Cook Islands	90	64	71	36
Niue	2	0	0	2
American Samoa	39	8	21	31
Samoa	2	1	50	1
Tonga	422	140	33	282
Fiji	2	0	0	2
Vanuatu	6	0	0	6
New Caledonia	185	25	14	160
New Zealand	17	4	24	13
Catalogue of Oceania	995	339	**34**	**692**

Table 2: Movement by individual whales between study sites.

Study sites	BB	HB	NZ	NC	VT	FI	SA	TG	NI	CI	FP	AS
Byron Bay (BB)		44	0	2	0	0	0	0	0	0	0	0
Hervey Bay (HB)			3	2	0	0	0	0	0	0	0	0
East Australia			3**	4	0	0+	0	0	0	0	0	0
New Zealand (NZ)				0	0	0*	0	0	0	0	0	0
New Caledonia (NC)					1	0	0	3	0	0	0	0
Vanuatu (VT)						0	0	2	0	0	0	0
Fiji (FI)							0	0	0	0	0	0
Samoa (SA)								1	0	0	0	0
Tonga (TG)									0	4	4	2
Niue (NI)										0	0	0
Cook Island (CI)											0	0
French Polynesia (FP)												3
American Samoa (AS)												

* Discovery marking documented interchange of 2 individuals between NZ and Fiji
**Discovery marking documented interchanges of 3 individuals between EA and NZ
+Discovery marking documented interchange of 1 individuals between Fiji and EA

Table 3: Direction of movement of individual humpback whales between the study sites of East Australia and Oceania with information concerning life and social history.

First region	Direction	Second region	Sex	Status	Social history
NC	**East**	**HB**			
1995, 1999		2000, 2001	Male	Young, then adult	Single, pod of 6, pod of 2
2000, 2005		2002	Male	Adult	Pod of 2, pod of 3, reproductive pod
NC	**East**	**BB**			
1999, 2000, 2001		2002	Male	Yearling, adult	Yearling + mother, single, pod of 2, reproductive pod
2001		2002	Male	Adult	Pod of 2, reproductive pod
HB		**NZ**			
1997, 1999, 2002		2004	Unknown	Adult	Single, pod of 2, pod of 5
NZ		**HB**			
2004		2004	Male	Adult	Pod of 3, pod of 2
2004		2004	Male	Adult	Mother, calf and escort, pod of 2
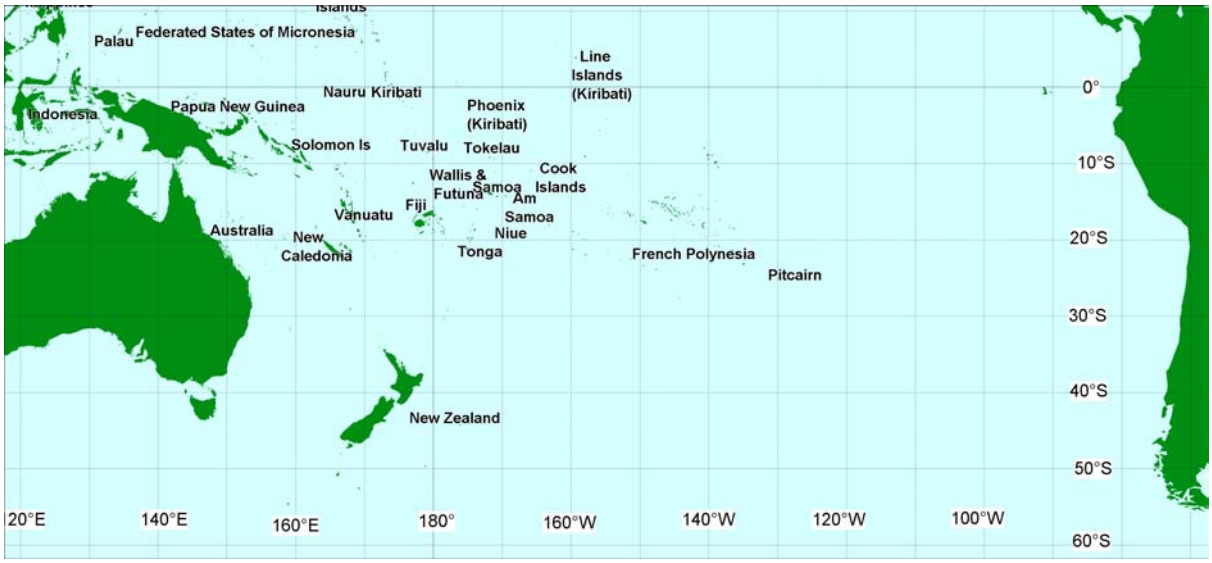
Figure 1 – Map of the study area